PROSPECT: **P**recision **R**eactor **O**scillation and **Spect**rum experiment

DAVID MARTINEZ CAICEDO on behalf of PROSPECT collaboration
ILLINOIS INSTITUTE OF TECHNOLOGY

NUFACT 2015
AUGUST 14th 2015

Outline

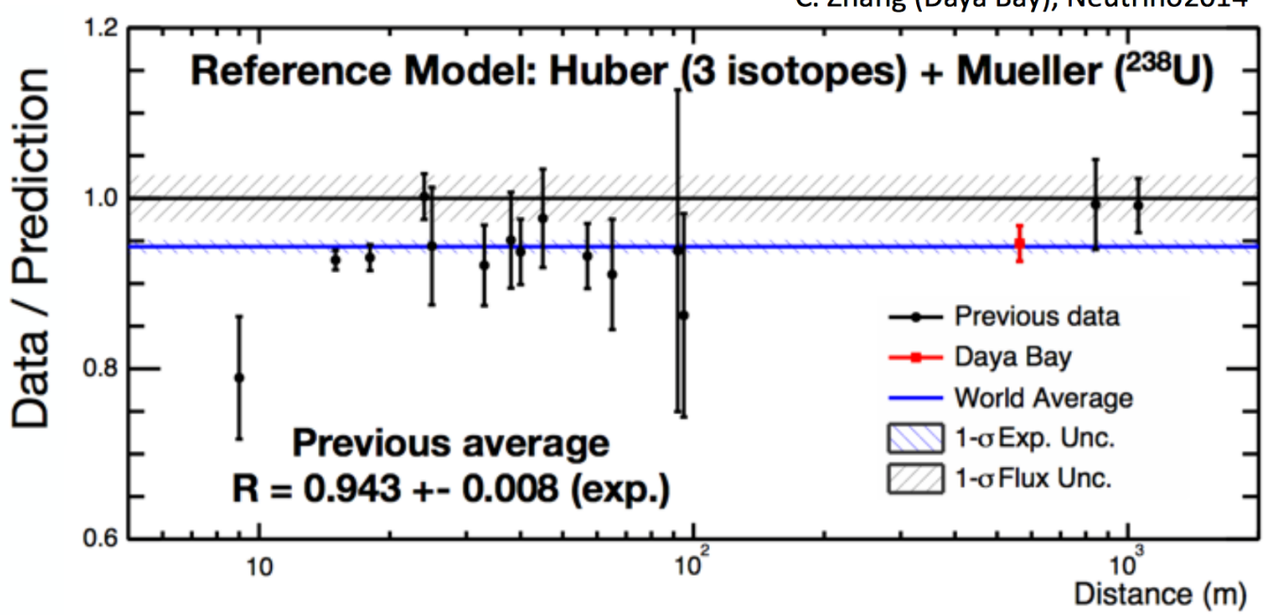
- Motivations: Why we need a short baseline reactor antineutrino experiment?
- The PROSPECT experiment
- PROSPECT: Detector components R&D
- PROSPECT: Physics goals

Why do we need a short baseline (SBL) reactor antineutrino experiment?

Reactor antineutrino anomaly

- Deficit in measured antineutrinos at different baselines.
- Measurement agrees between different detectors technologies and reactors.
- ~6% deficit with respect to 2011 Huber/ Mueller flux prediction.

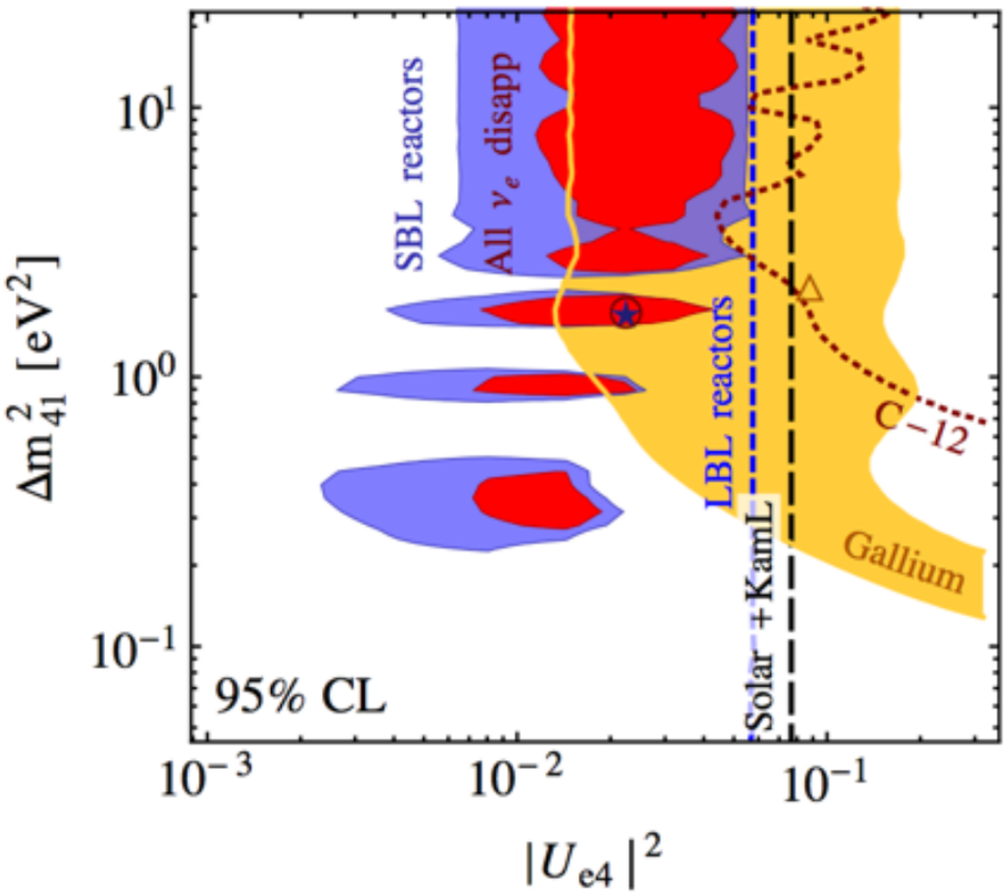
C. Zhang (Daya Bay), Neutrino2014

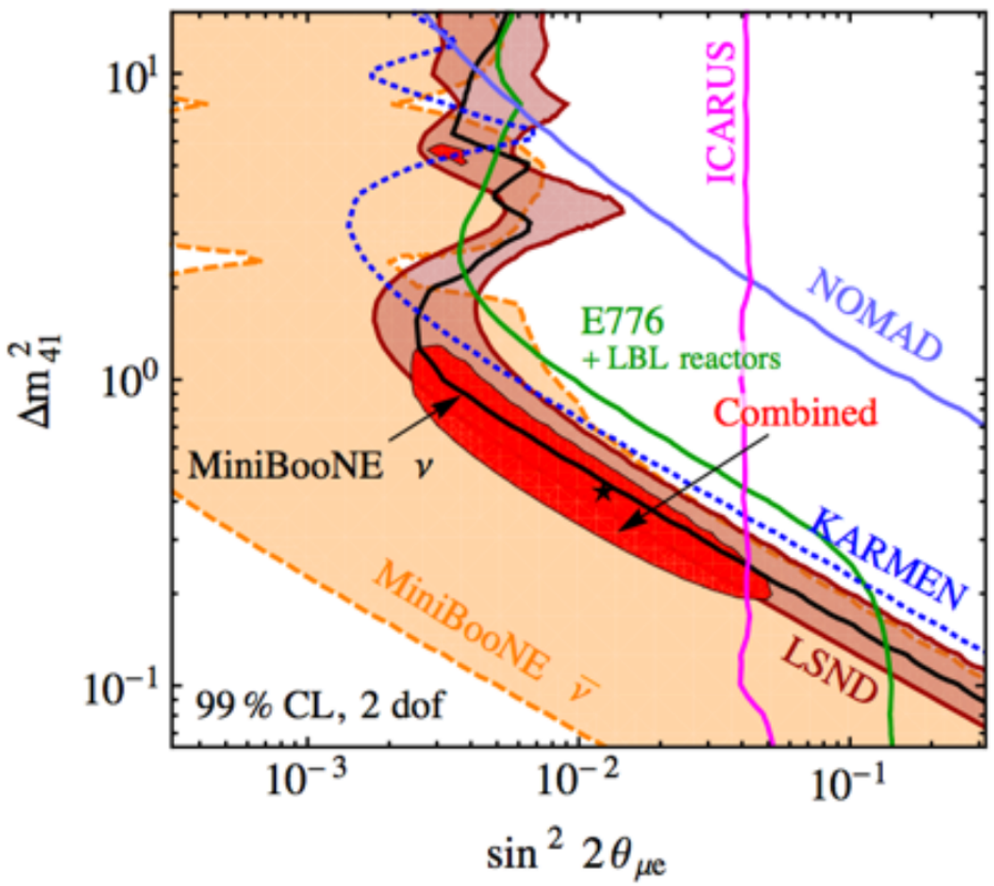


- **WE NEED MORE DATA TO UNDERSTAND THESE ANOMALIES!**

Reactor antineutrino anomaly

- Deficit could come from SBL sterile neutrino oscillations
- Reactor anomaly hints a similar parameter space as other anomalies: Gallium, MiniBooNE, LSND.
- Null results from ν_μ disappearance in similar region leave an ambiguous current picture

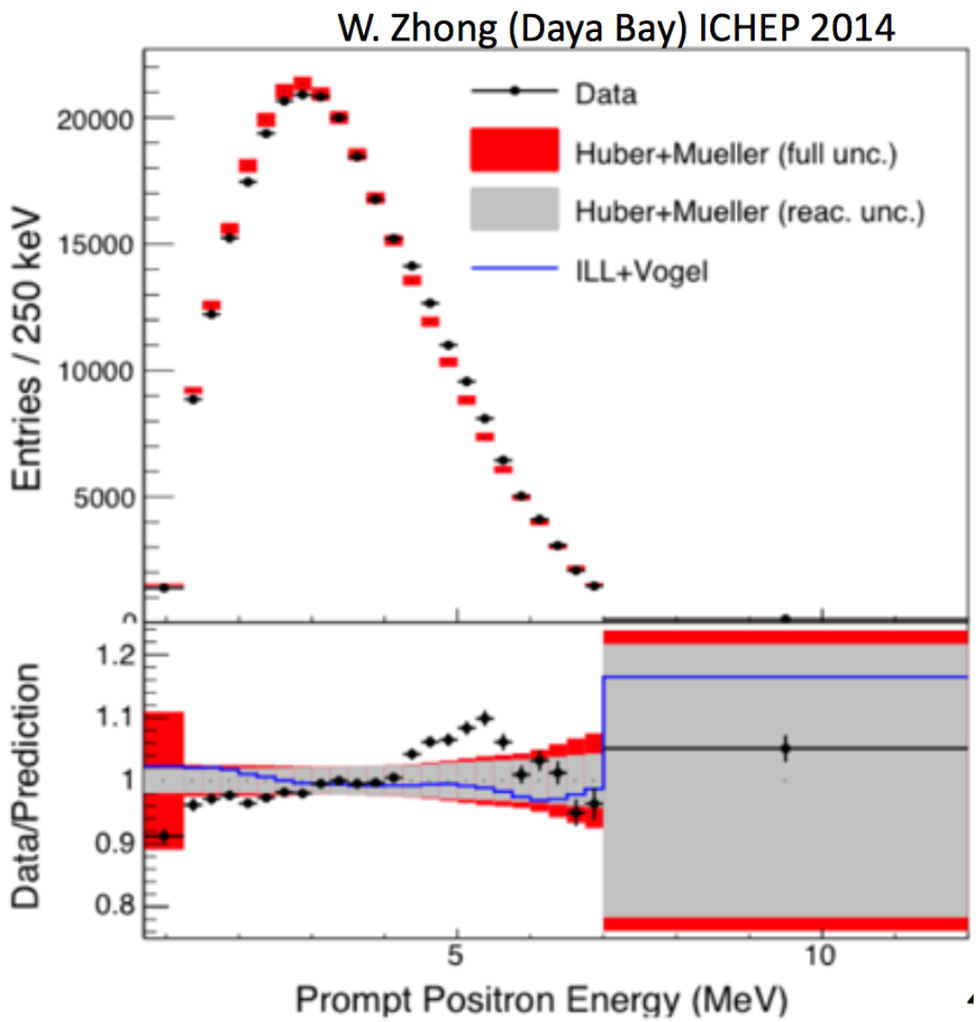




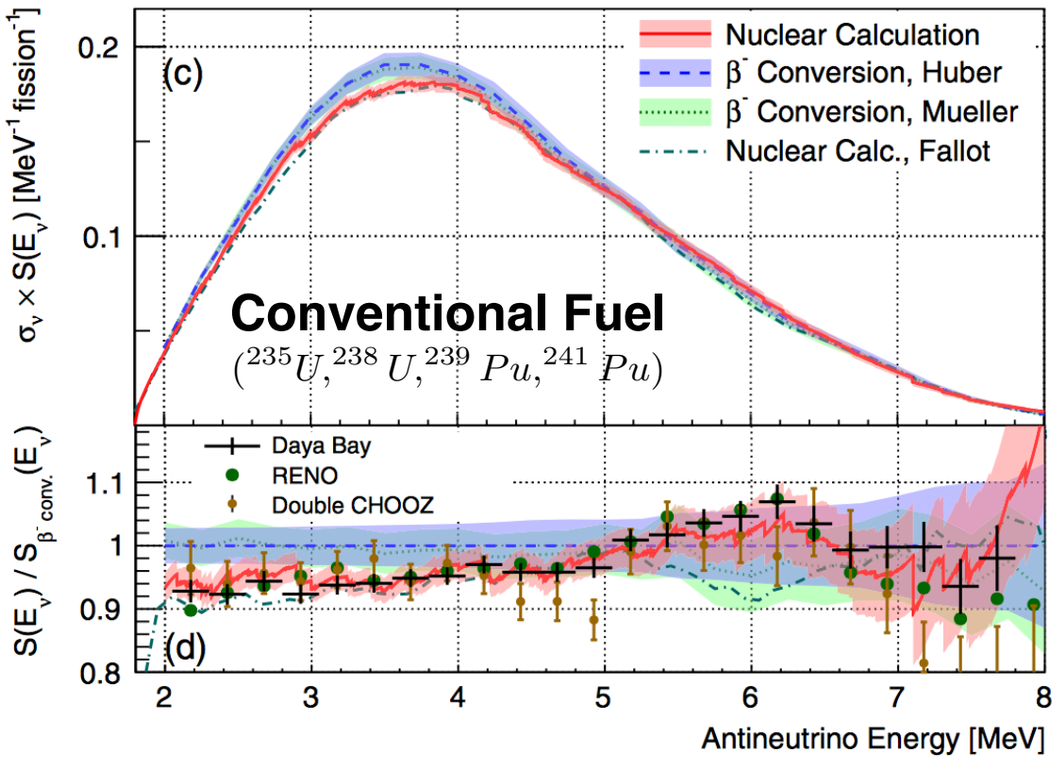
- **WE NEED MORE OSCILLATION DATA AT SMALL L/E(~m/MeV)!**

Reactor antineutrino anomaly

- Excess of events around 5 MeV in the IBD prompt energy spectrum



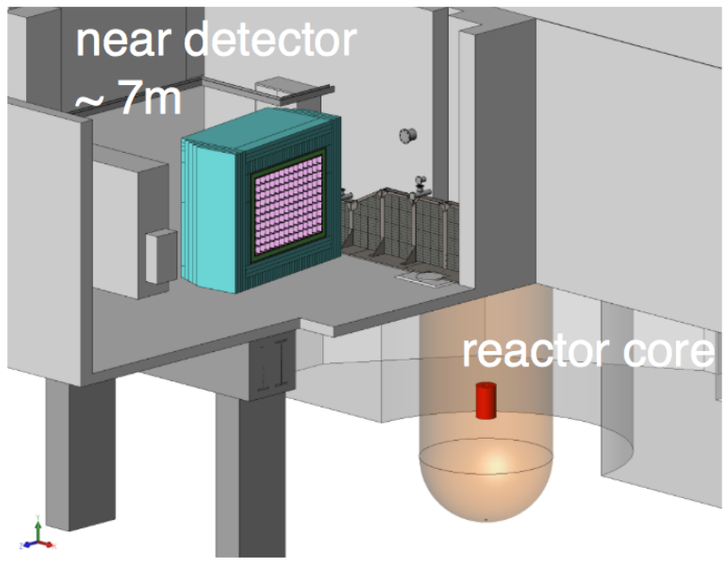
Dwyer and Langford, PRL **114** 012502 (2015)



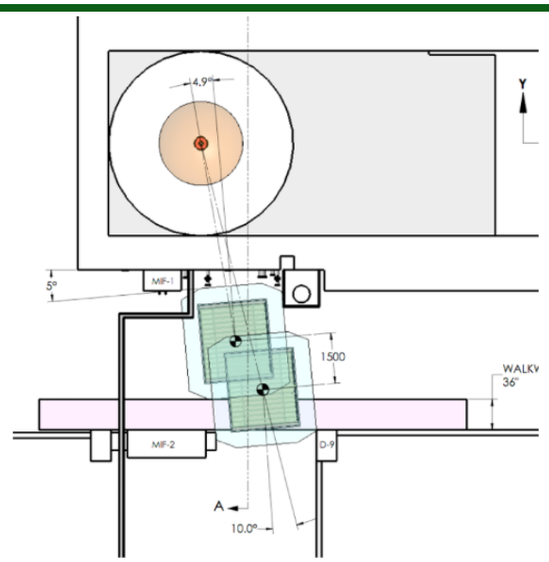
- What could be causing the excess around 5 MeV? Problems in the beta to $\bar{\nu}_e$ conversion
- Dwyer-Langford-> **Ab initio calculation** of the antineutrino spectrum using beta-branch data bases.
- **Beta conversion-> Measure beta spectrum directly and convert to $\bar{\nu}_e$ using virtual beta branches**

The Precision Reactor Oscillation and Spectrum Experiment

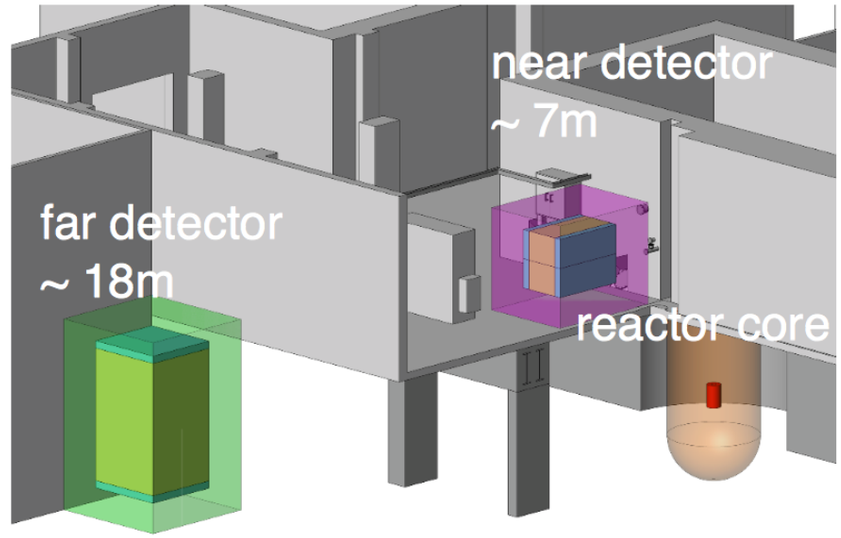
PROSPECT Experiment



phase 1

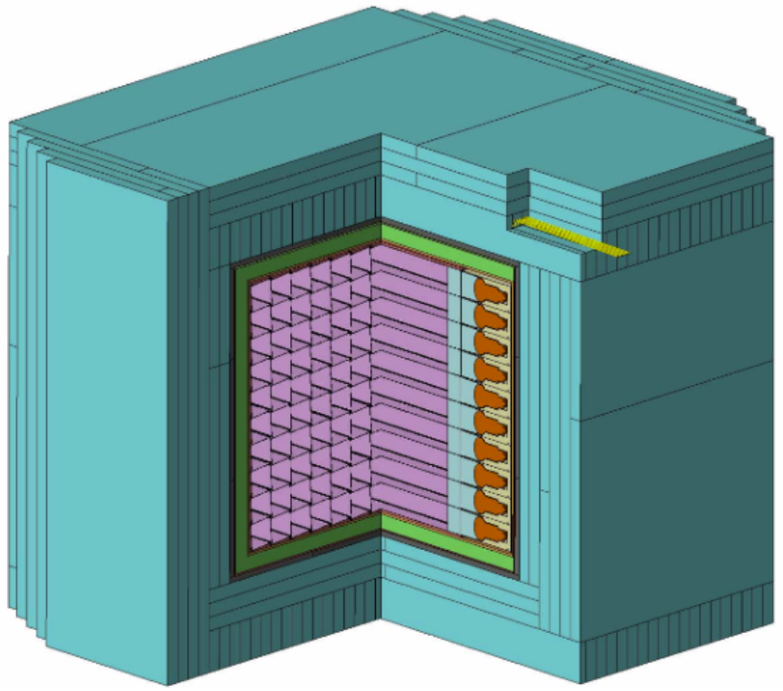


phase 1+



phase 2

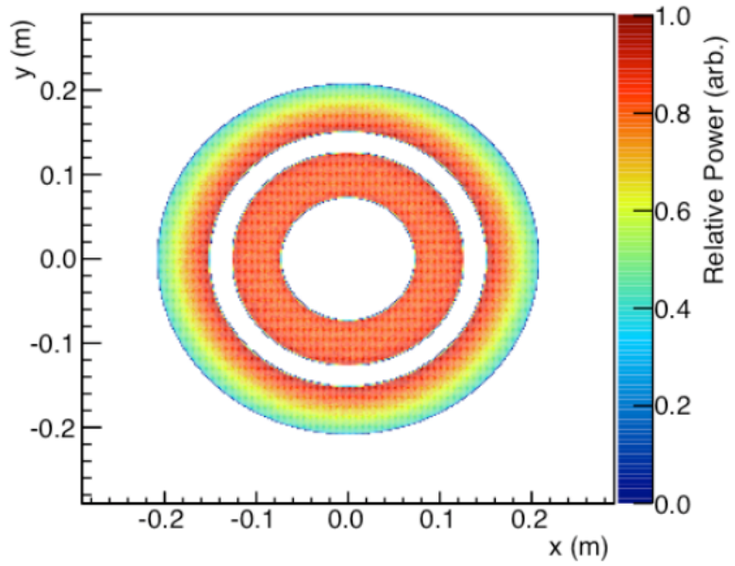
- **Goals:** Search for short baseline $\bar{\nu}_e$ oscillations
- Make precise measurement of the ^{235}U antineutrino spectrum

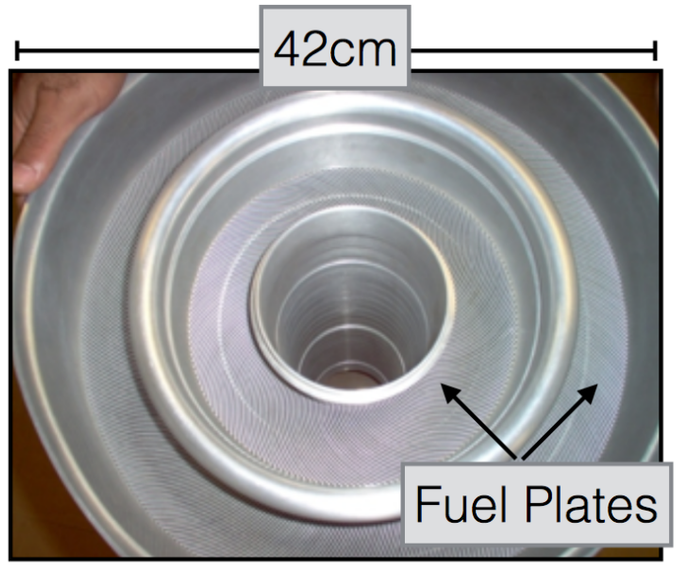


- **MULTI-PHASED APPROACH:**
- **Phase 1**: Near Detector
- **Phase 1+**: **Moveable** Near Detector
- **Phase 2:** Near + Far detector
- Mitigate risks
- Systematic control and increased physics reach

The antineutrino source: High Flux Isotope Reactor at Oak Ridge National Lab

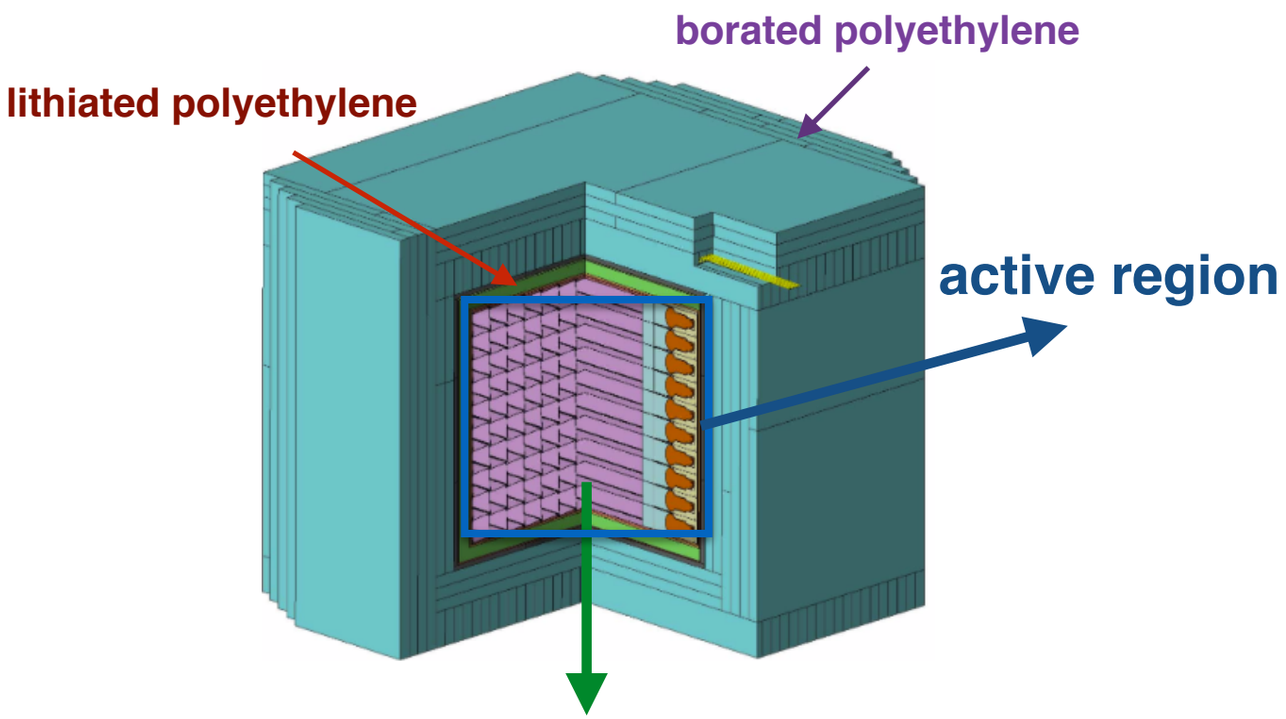
- Research reactor at ORNL. Operating power 85 MW
- Compact cylindrical core: 42 cm X 50cm.
- 41% up-time (5 yearly cycles)
- Highly enriched uranium (HEU): ^{235}U



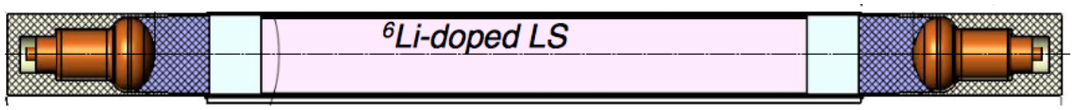


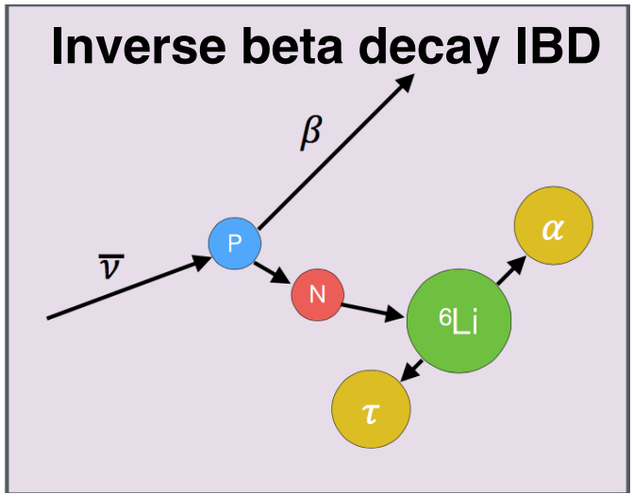
Antineutrino detection in PROSPECT

- 140 optically decoupled cells (14*10)
- Cell dimension~: 15 cm * 15 cm *100 cm
- Specularly reflecting cell walls
- Segmented liquid scintillator **target region**: 2.5 tons for near detector (Phase 1)



- Moveable: 7-11 m baselines
- Multi-layer shield to suppress n,γ
- Inverse beta decay on Li-doped liquid scintillator.
- **Goal**: Achieve good position and energy resolution.



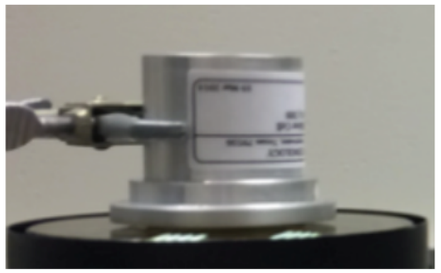


prompt signal: 1-10 MeV positron from inverse beta decay

delay signal: 0.6 MeV signal from neutron capture on ^{6}Li

PROSPECT development status

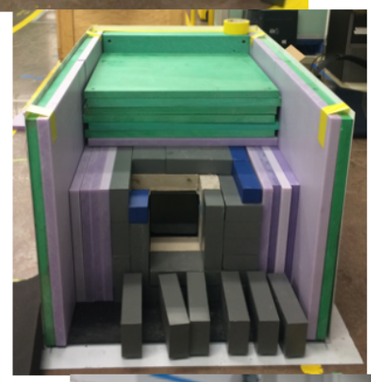
PROSPECT-0.1 Y,H
Aug 2014
Spring 2015
Characterize LS



5cm
0.1liter
LS, ^{6}LiLS

PROSPECT-2 H
Winter 2014-15
Aug 2015
Background studies

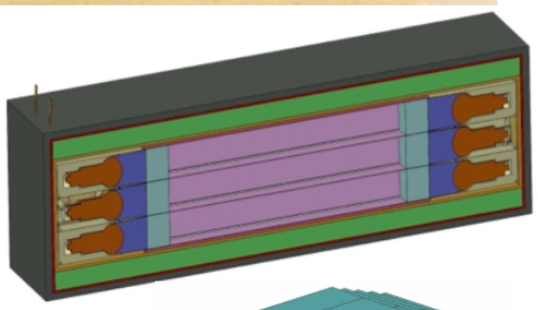
12.5cm
1.7 liter
^{6}LiLS



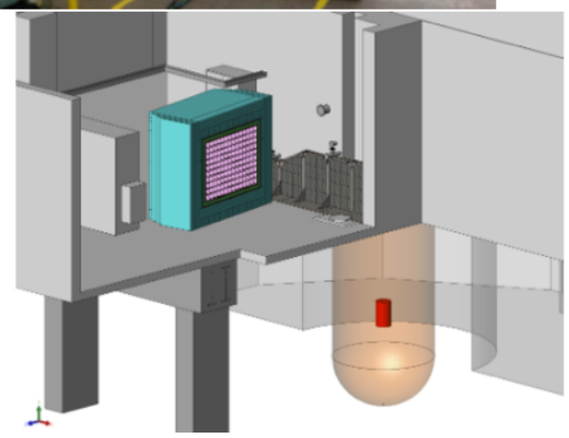
PROSPECT-20 Y,H
Spring -Summer 2015
Characterize segment

1m
23 liter
LS, ^{6}LiLS

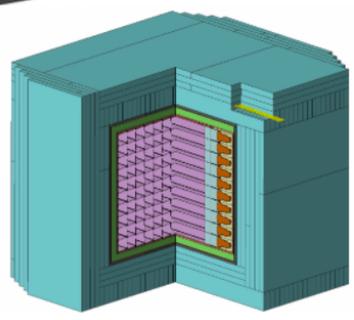
PROSPECT-Nx20 H
Late 2015*
Mechanical prototype



1m
Nx20 liter
^{6}LiLS segments



PROSPECT-2k H
Late 2016*



1m
2.5 tons
^{6}LiLS segments

*technically driven schedule

Oscillation physics

Absolute spectrum

HFIR = H , Yale = Y

SBL reactor experiment key requirements

- **Understanding of:**

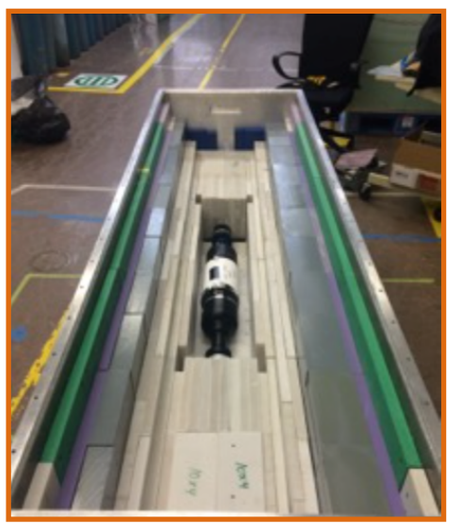
- Energy and position resolution.

- Energy scale

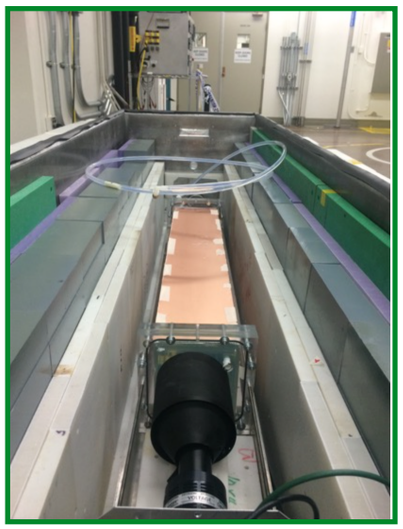
- Backgrounds at on-surface near reactor location.

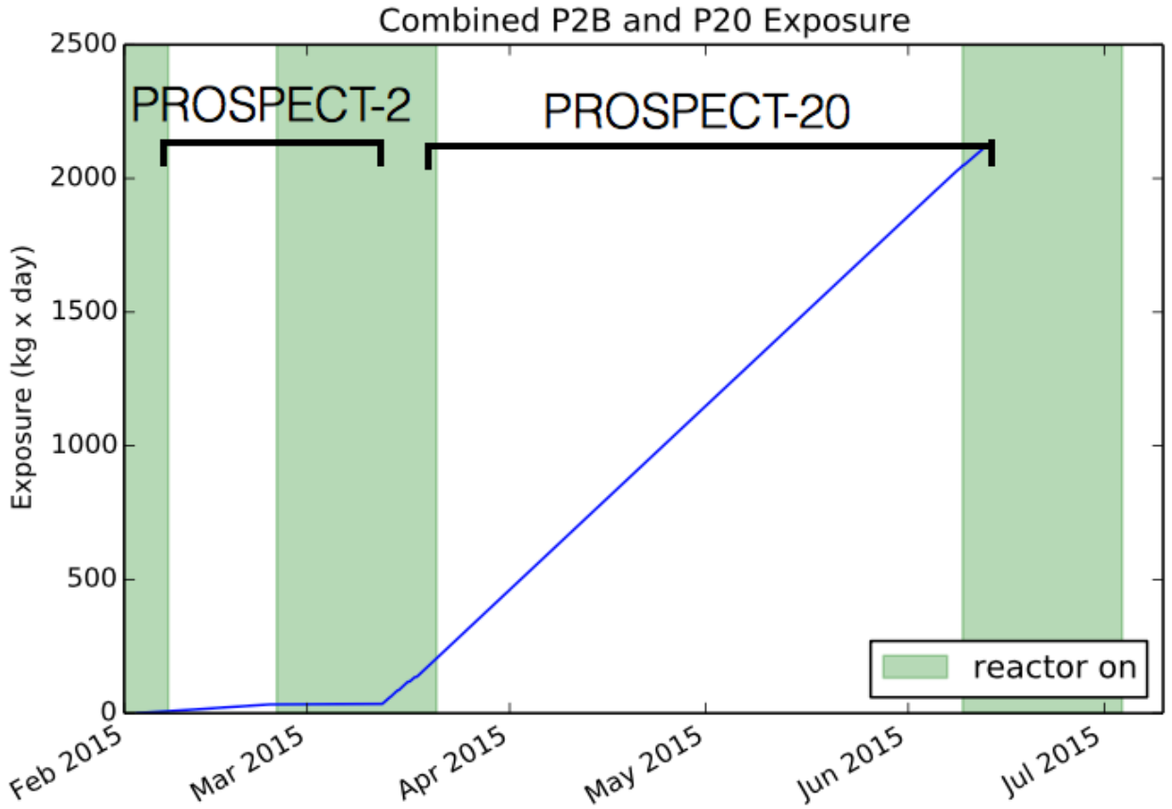
Prototyping program has demonstrated key components in all of this areas :)

PROSPECT-2 at HFIR
shielding:poly,Pb,Bpoly



PROSPECT-20 at HFIR
Shielding:poly,Pb,Bpoly,waterbricks

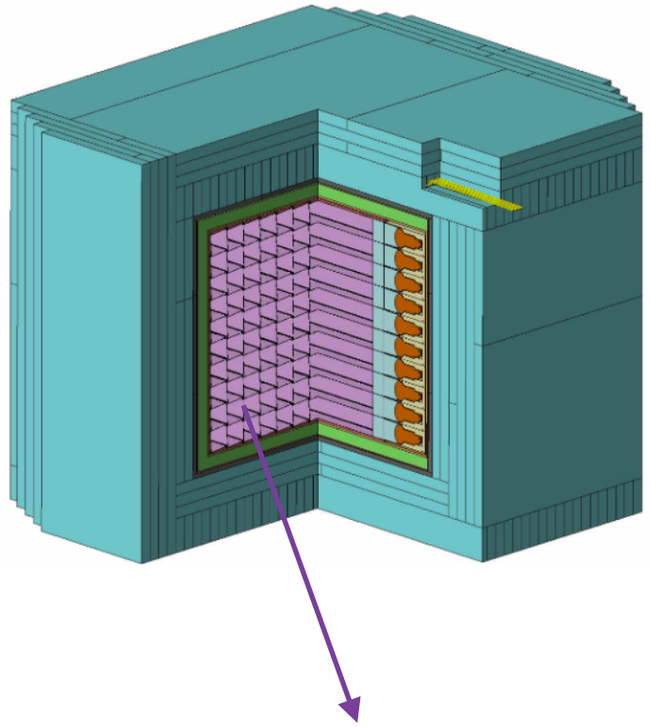


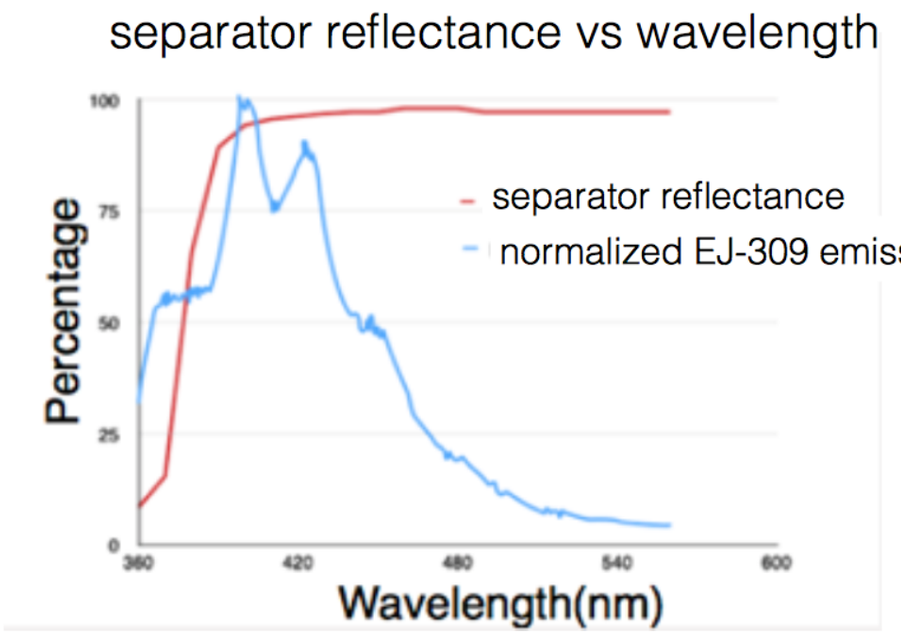


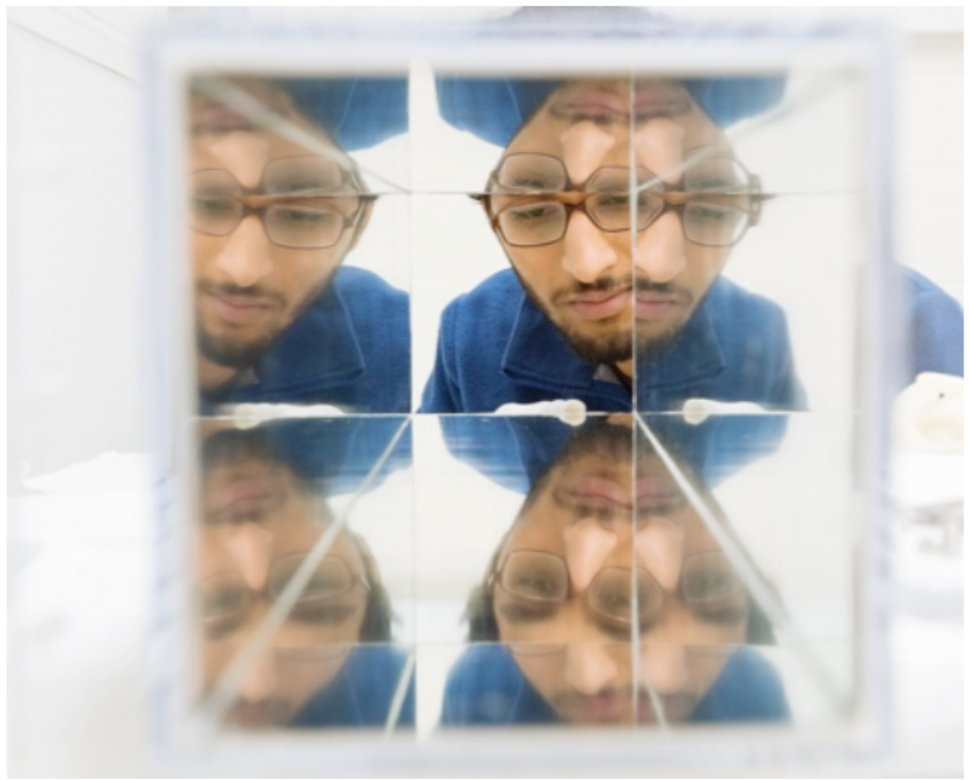
PROSPECT : Detector components R&D

Optical separators

- Low inactive mass and high reflectance in Li-loaded EJ309 to improve energy resolution and light collection.
- Test compatibility of optical separators (different materials) to ensure long term LiLS performance.
- In process of validation: fabrication method for separators.

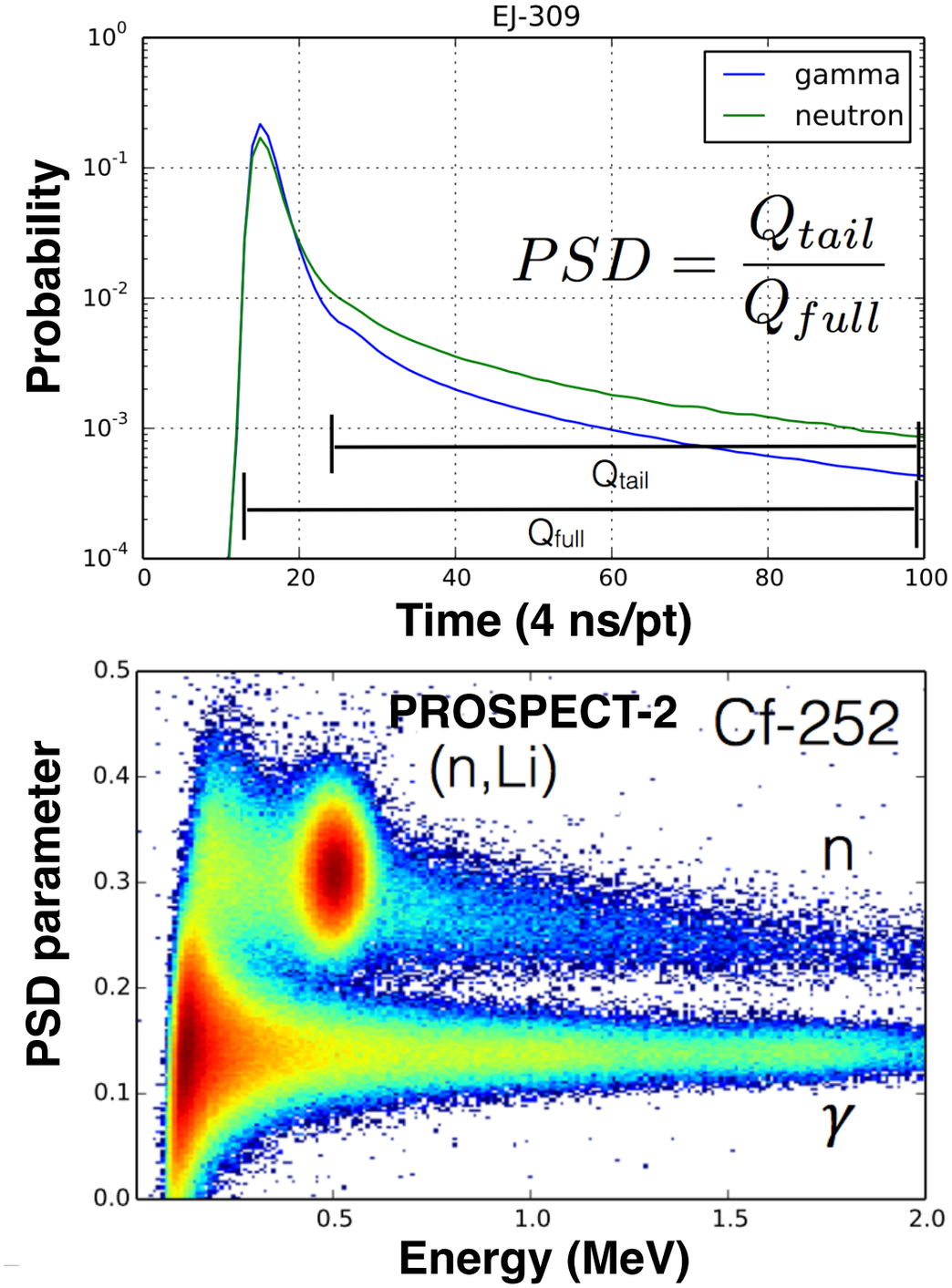






Pulse Shape Discrimination (PSD): Signal selection and background rejection

1. Through PSD, capability of distinguishing nuclear recoils from electromagnetic interactions
2. PSD can also be used to identify time-correlated proton recoil energy depositions caused by fast neutrons



PSD Signatures

Inverse Beta Decay

γ-like prompt, n-like delay

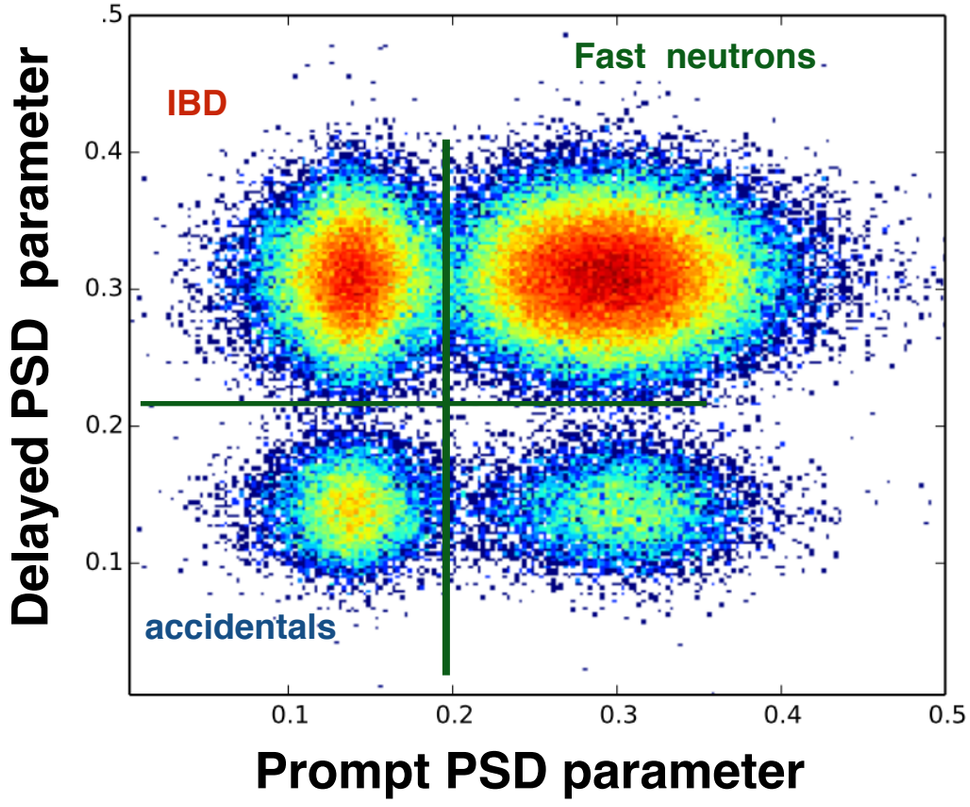
Fast Neutron

n-like prompt, n-like delay

Accidental Gammas

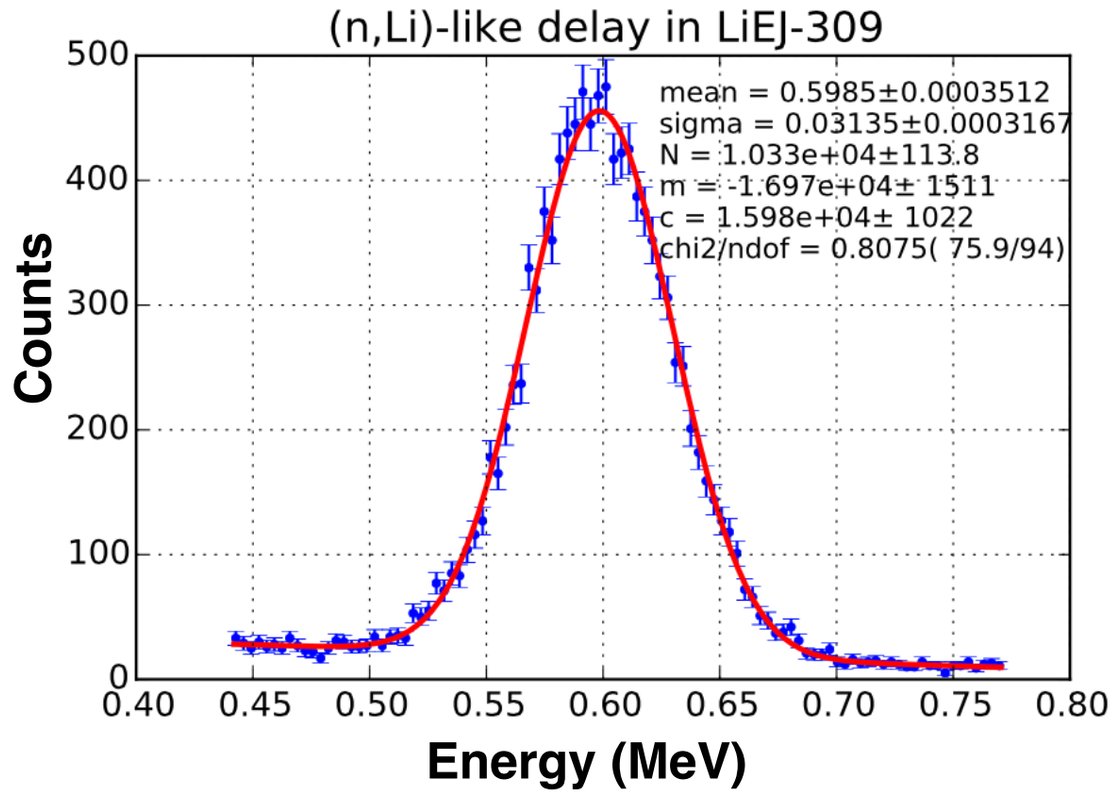
γ-like prompt, γ-like delay

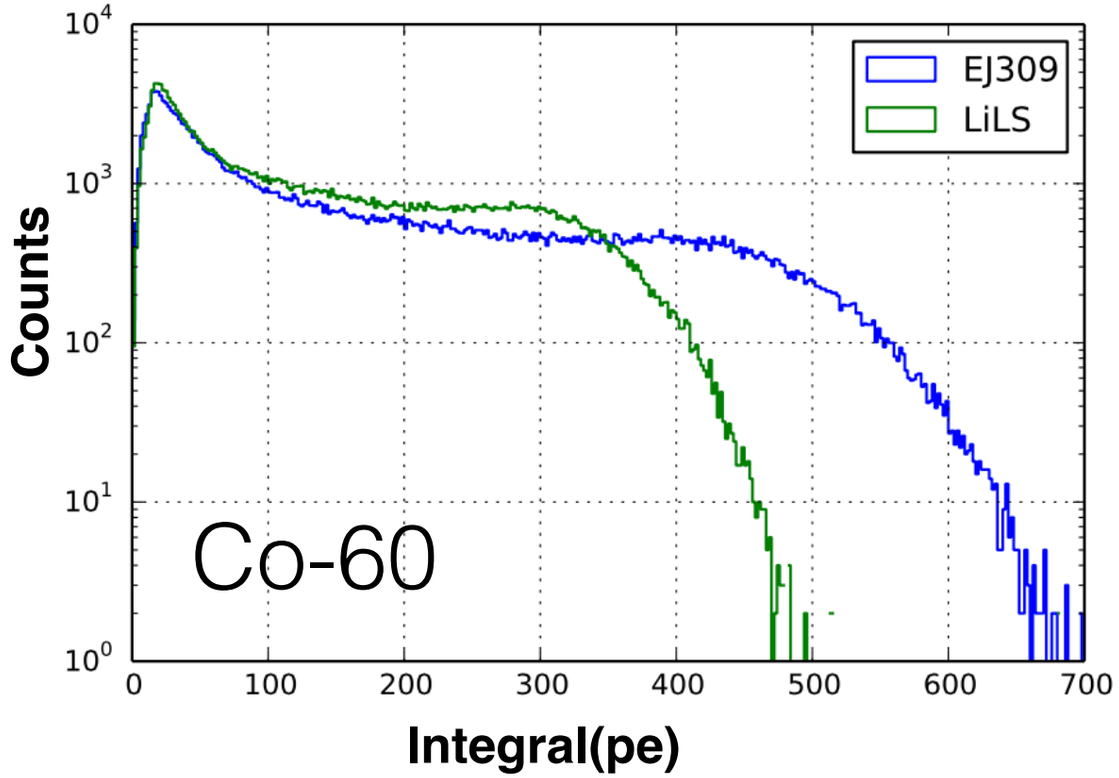
PROSPECT-2

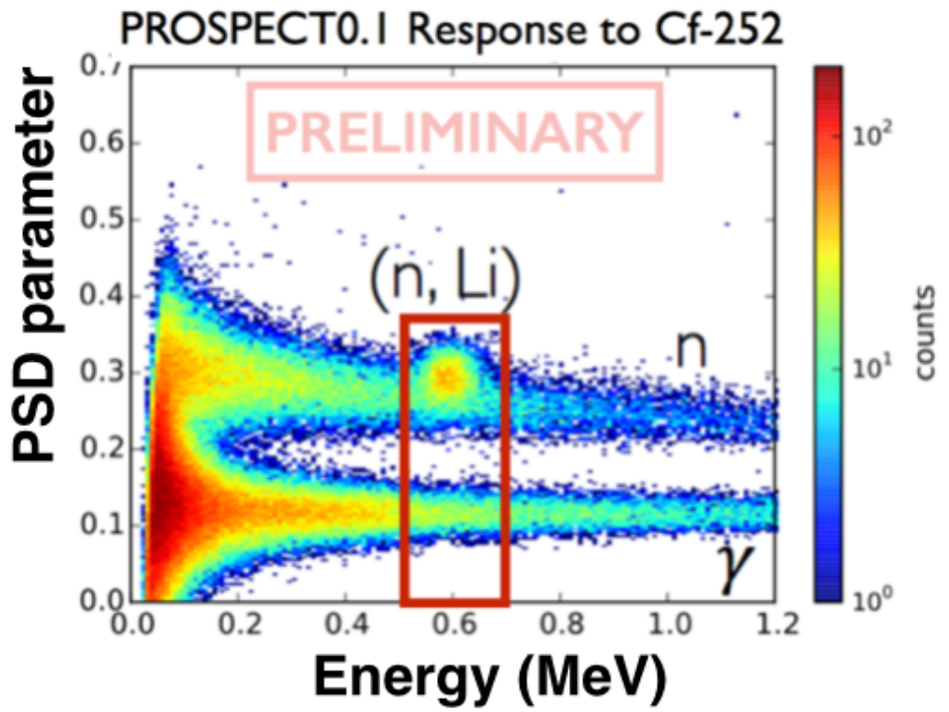


Liquid scintillator

- Light yield EJ309: 11500 ph/MeV
- Light yield LiLS measured : 8200 ph/MeV.
- Energy resolution (σ/E) of 5.2% at 0.6 MeV.

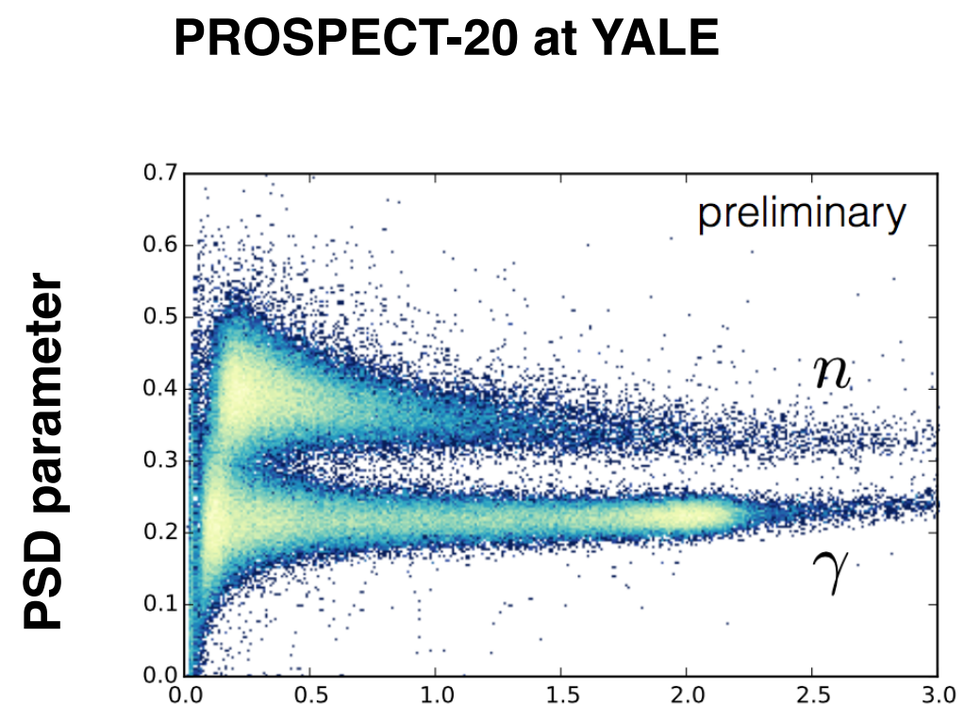


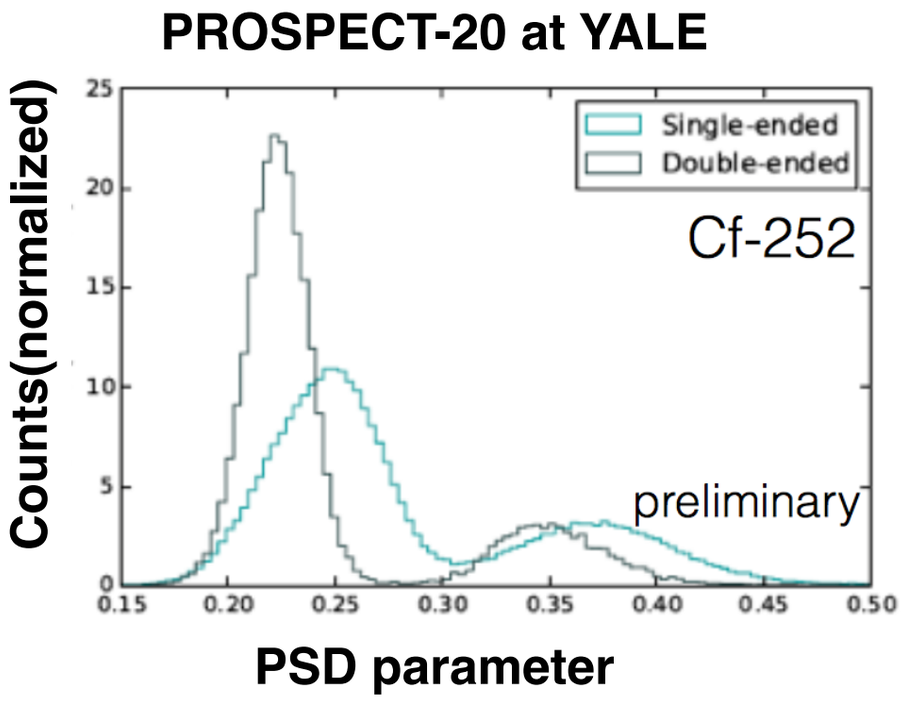


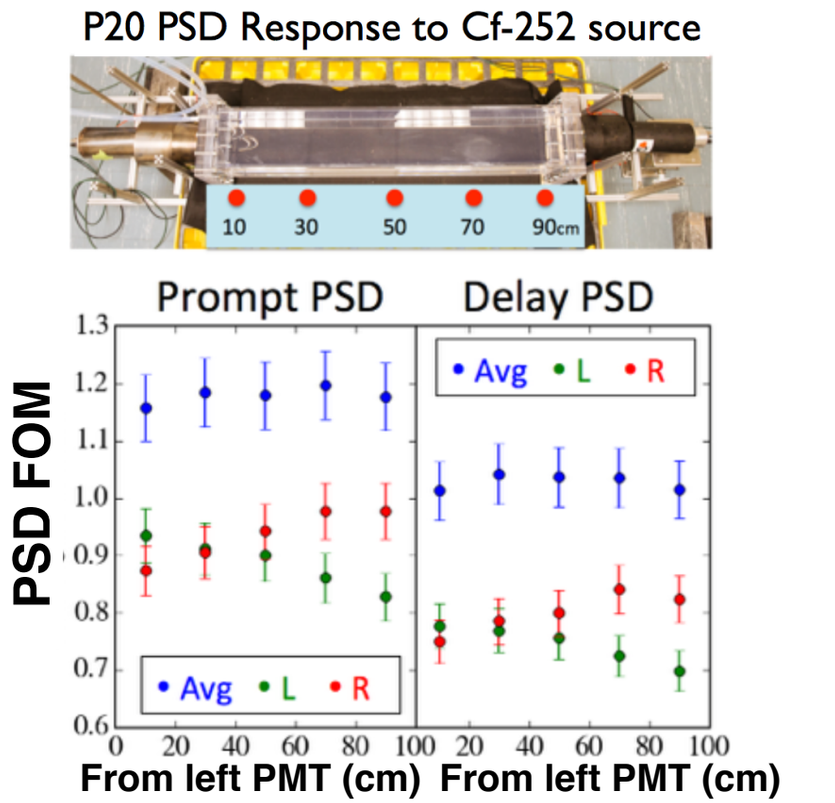


Double ended readout

- Uniform optical collection through the cell
- Improvement on PSD : Maintained over large cell size.
- Good background reduction : Reject many neutron-related, reactor gamma backgrounds
- Figure of Merit: $FOM = \frac{\mu_2 - \mu_1}{FWHM_1 + FWHM_2}$

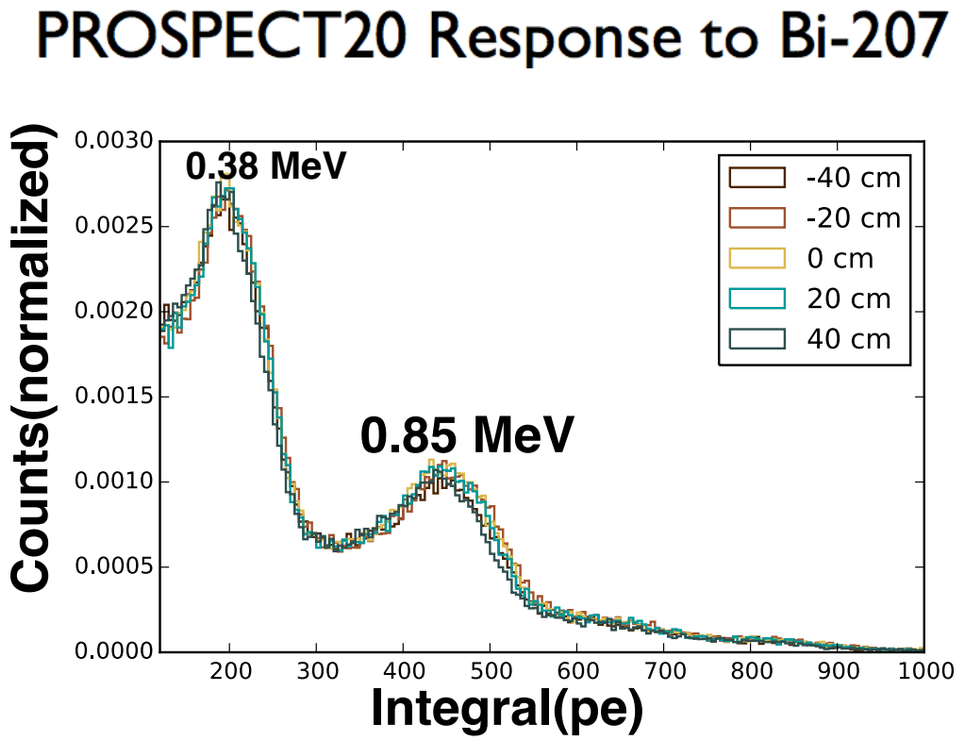


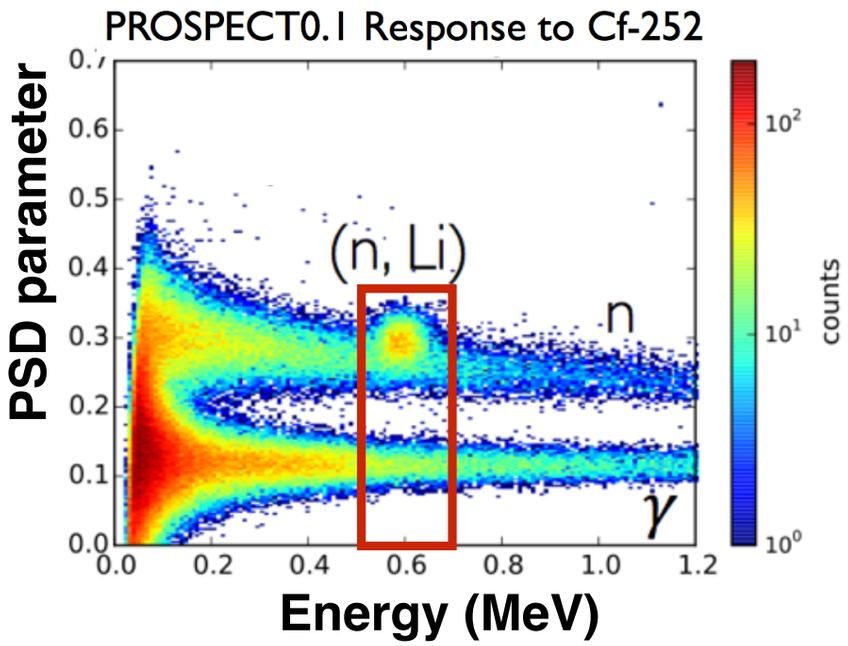


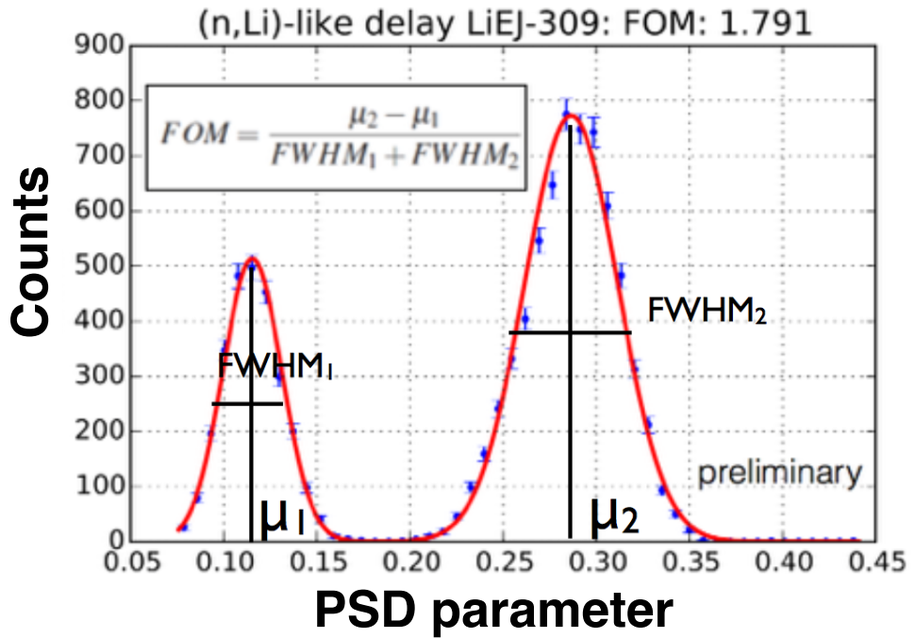


Energy response

- High light yield for **Li-loaded EJ309**
- **8200 photons/MeV** (11500 for unloaded EJ309) good enough to reach full cell 4-5% resolution.
- Excellent uniformity along full cell.
- **Clear neutron capture peak on LiLS at low energy and high PSD. PSD FOM at (n, Li) is 1.79**

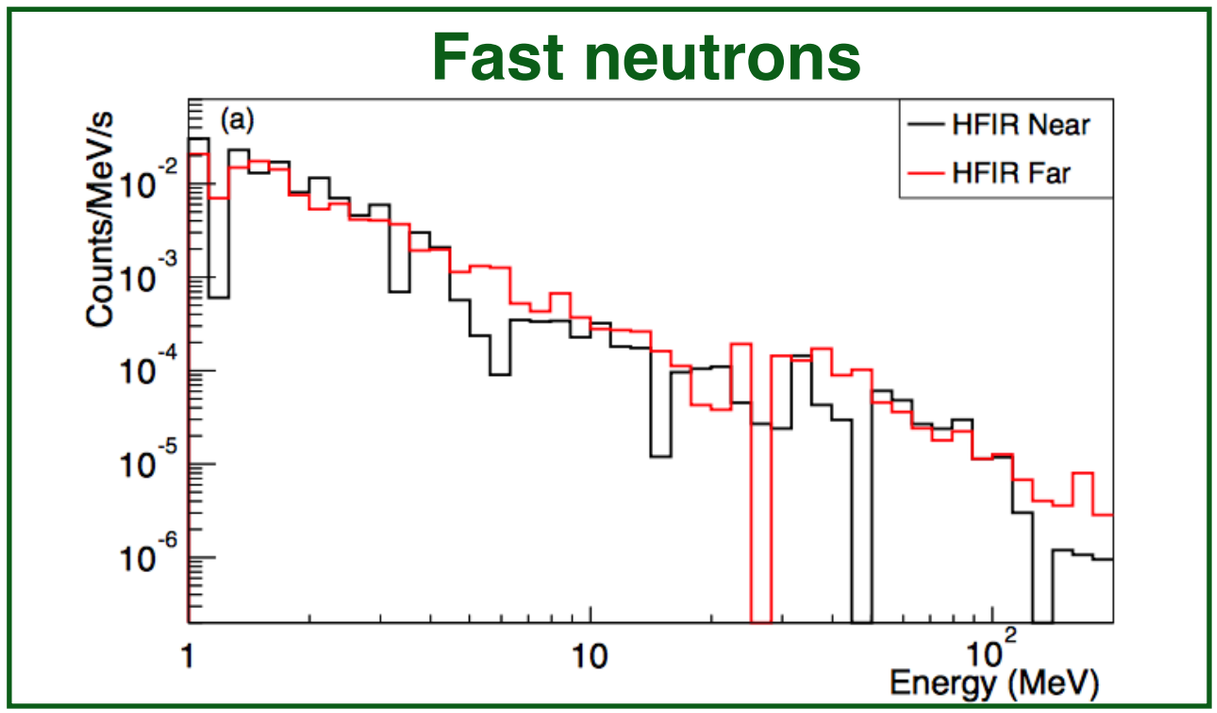


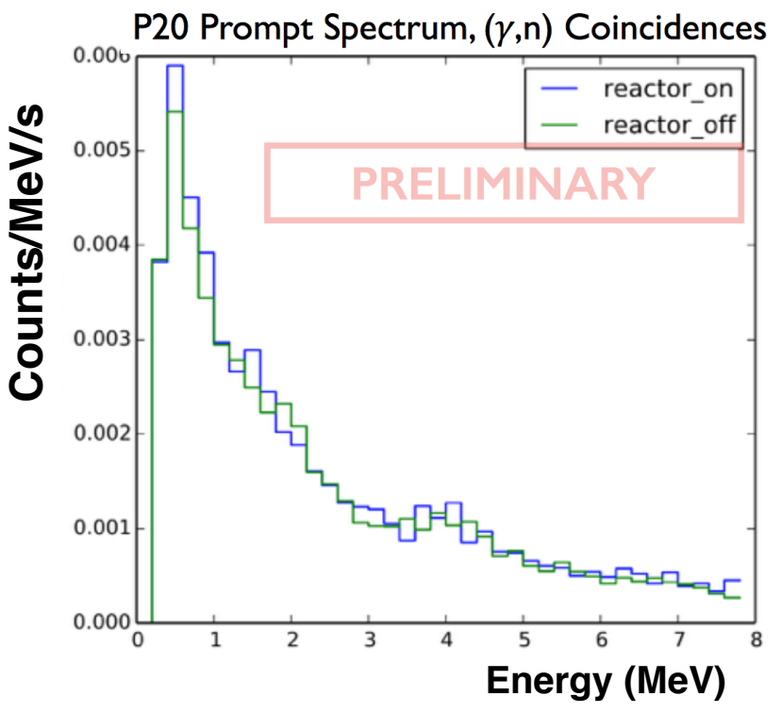


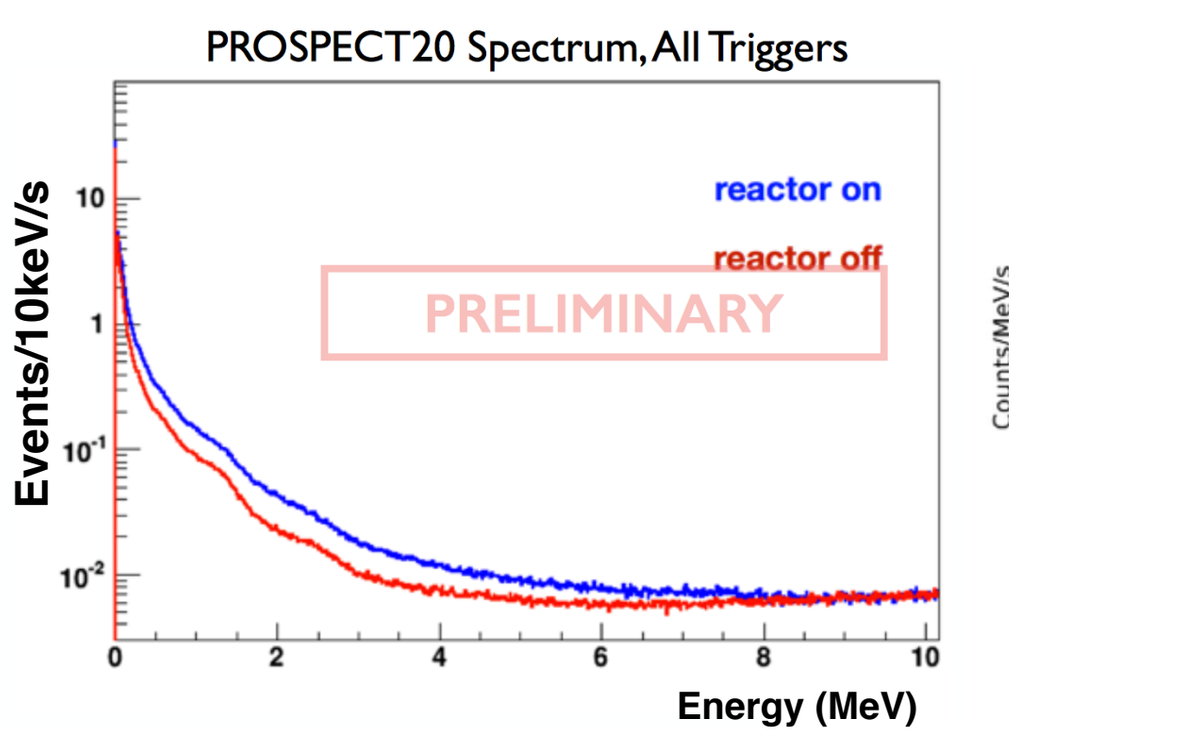


Backgrounds at HFIR

- Cosmogenic fast neutrons.
- Reactor-related high energy gammas (accidental coincidences).
- Natural radioactivity backgrounds $(^{40}K, ^{232}Th)$ coming from the PMT glass, metal building materials surrounding the active detector target.
- Backgrounds are well modeled in simulation and validated with PROSPECT-2 & PROSPECT-20.







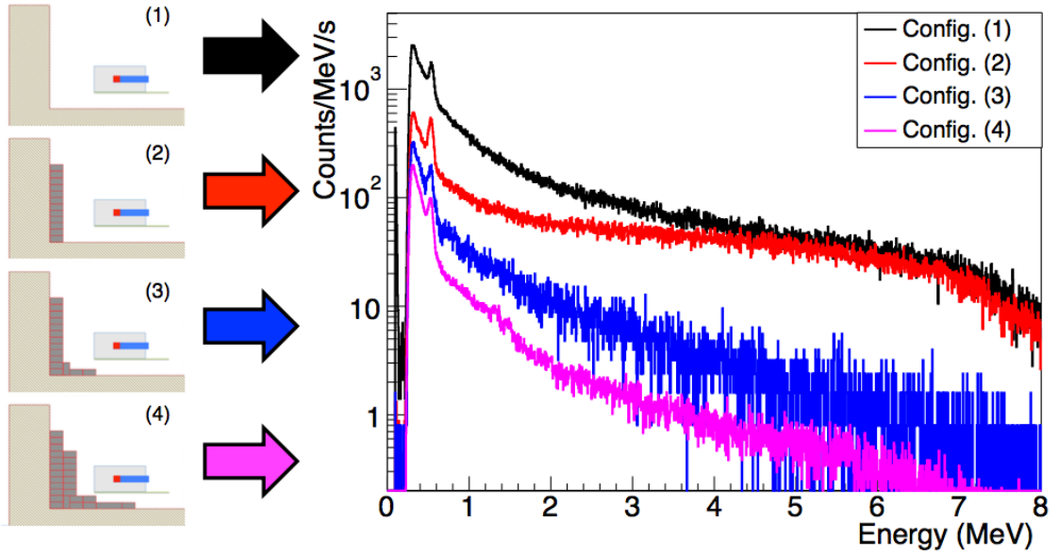
For more detailed info: Background Radiation Measurement at High Power Research Reactors (arXiv1506.03547)

Background subtraction techniques

- PSD, timing coincidence and fiducialization will allow us to reject many of the previous backgrounds **:)**

- Fiducialization to control near-surface backgrounds.

- Designed localized shielding to suppress cosmogenic and reactor correlated backgrounds.



PROSPECT: PHYSICS GOALS

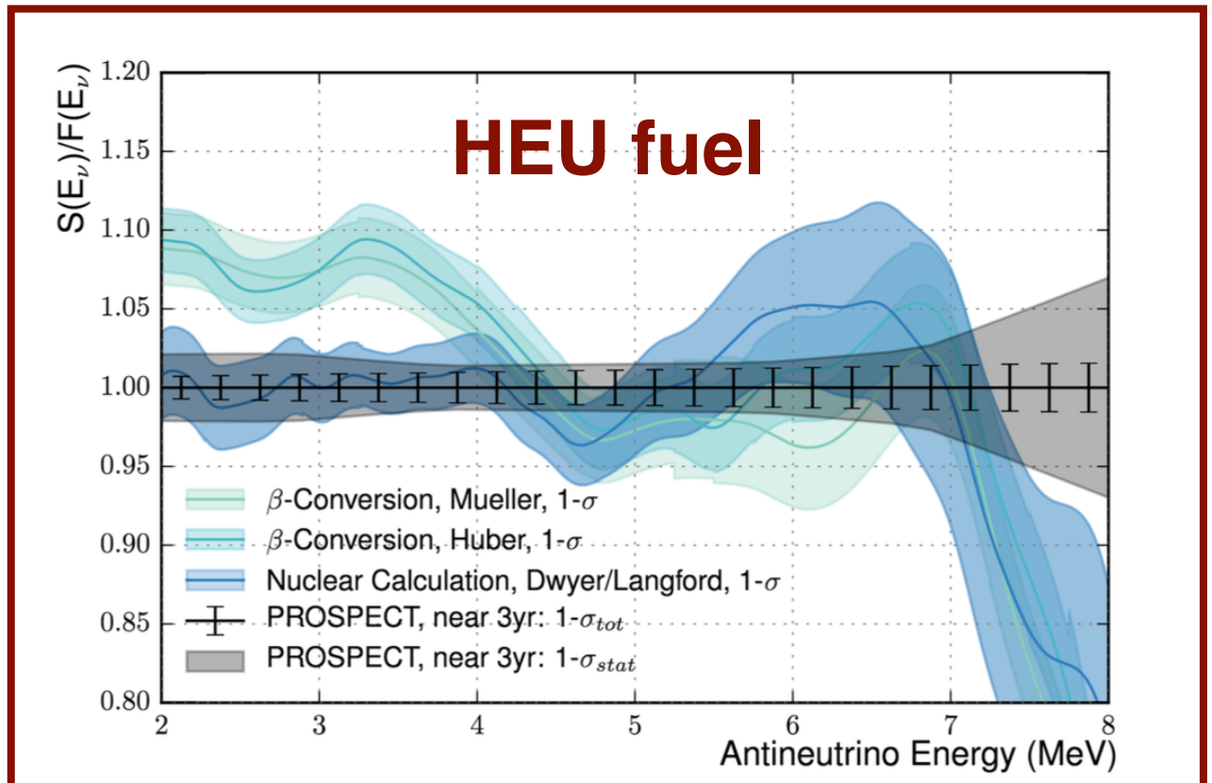
PROSPECT HEU antineutrino spectrum measurement

- Constraint different reactor models using the information form the HEU reactor.

- **HFIR HEU** -> Only 1 isotope, no time dependence (Daya Bay, RENO multiple isotopes).

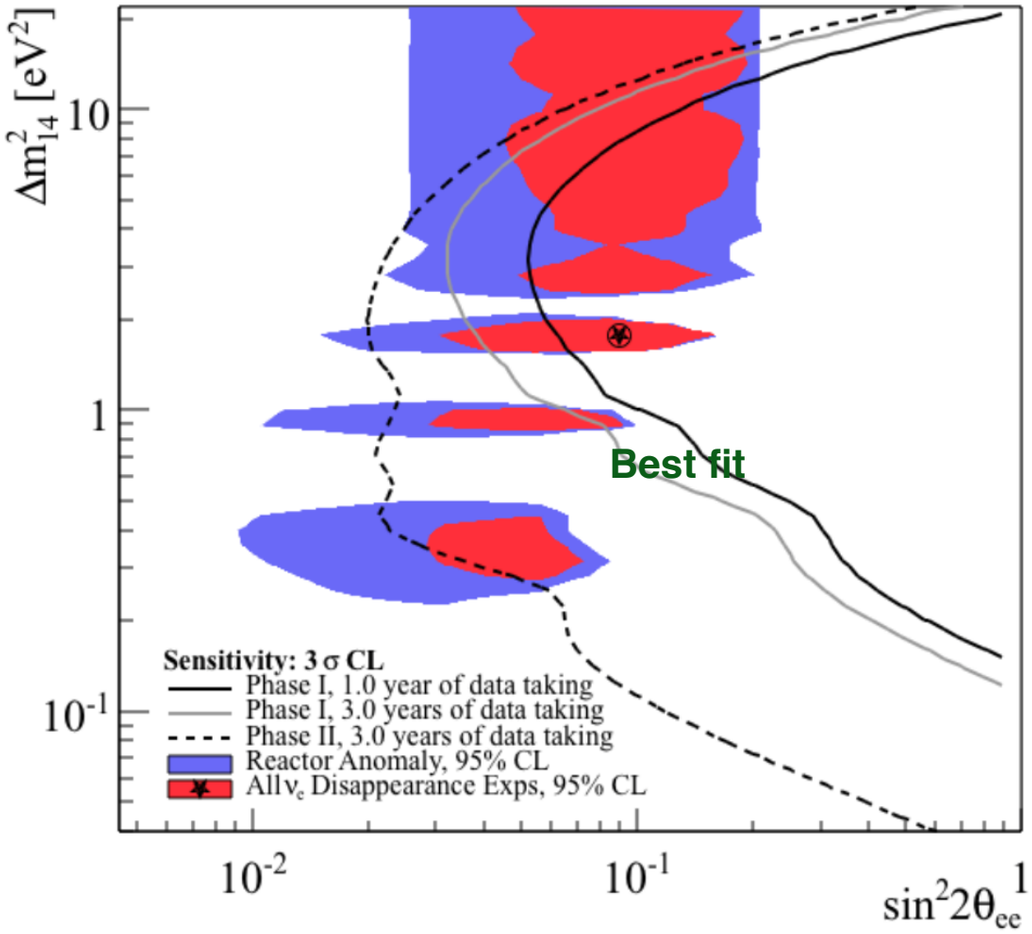
- Antineutrino spectrum energy resolution goal: 4-5%

- High statistics due to proximity to reactor (~115K IBD/year projected for PROSPECT Phase I)

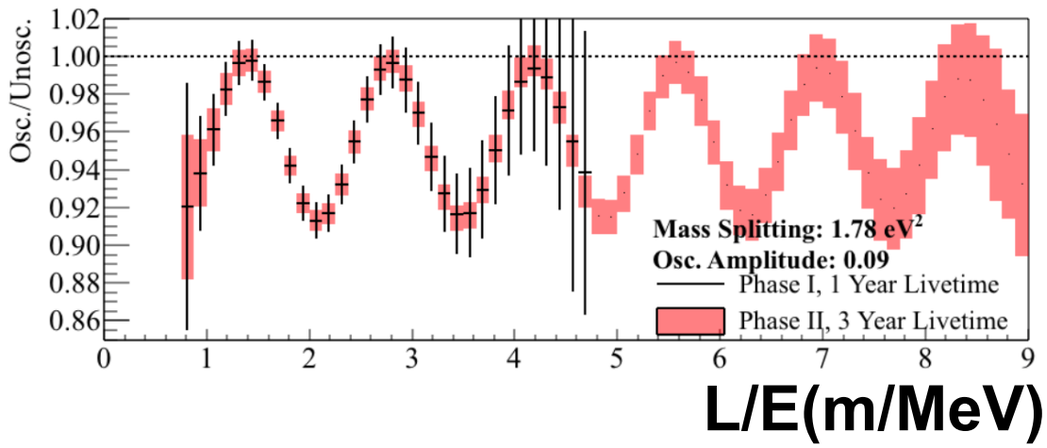


PROSPECT SBL oscillations sensitivity

- Assumptions:
- 4.5/sqrt(E) Energy resolution
- 20 cm position resolution
- 1:1 Signal:Background ratio.
- If sterile neutrino is where **global fit suggest**, PROSPECT Phase 1 has the discovery potential with one year data taking with 3 σ CL.
- Independent of absolute spectral shape or normalization: pure relative L/E measurement

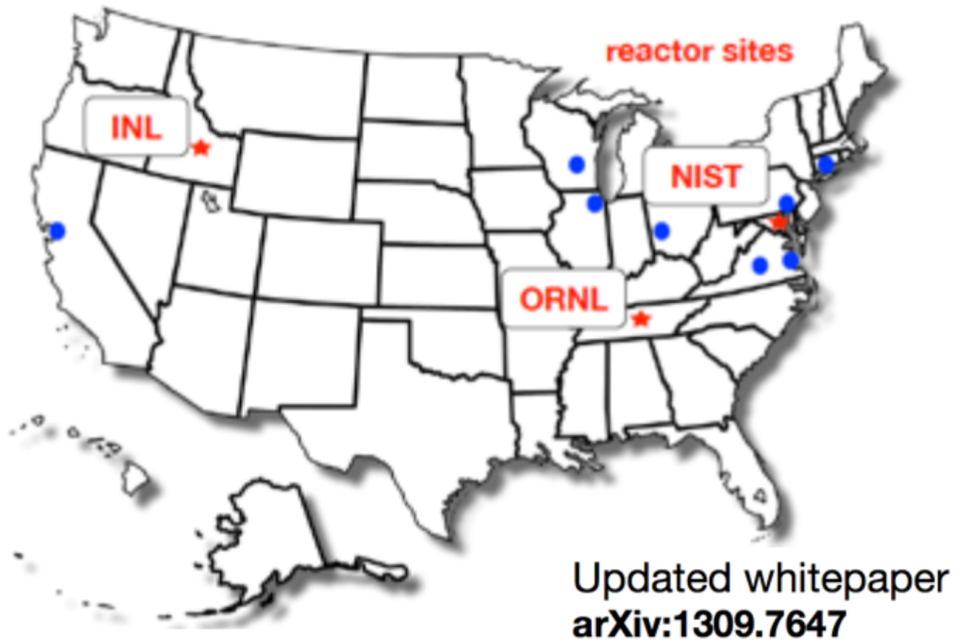


Simulated PROSPECT data, binned in L/E; Stat err. only



PROSPECT Collaboration

- *Brookhaven National Laboratory*
- *Drexel University*
- *Illinois Institute of Technology*
- *Lawrence Berkeley National Laboratory*
- *Lawrence Livermore National Laboratory*
- *Le Moyne College*
- *National Institute of Standards and Technology*
- *Oak Ridge National Laboratory*
- *Temple University*
- *University of Tennessee*
- *University of Waterloo*
- *University of Wisconsin*
- *College of William and Mary*
- *Yale University*
- ***63 collaborators! 9 Universities & 5 National Labs***



Summary

- We need more data to constrain the “Reactor Anomaly” further!
- PROSPECT has built several test detectors and is ready to scale up to Phase 1.
- Segmented Li-doped LS design will provide excellent energy and position resolution.
- PROSPECT will provide a unique measurement of the ^{235}U reactor antineutrino spectrum for use in improving reactor flux predictions.
- PROSPECT Phase I will be able to test the existence of ν_s with one year data taking at 3σ CL.
- PROSPECT oscillation physics program (ν_e disappearance) is complimentary to current/future neutrino efforts at Fermilab SBN program(ν_μ disappearance and ν_μ to ν_e appearance)

Thanks!
Obrigado!
Gracias!

Backup

World-wide SBL reactor efforts

- Mainly HEU fuel for majority of experiments.
- Detector locations < 20 meters.
- Multiple technologies to obtain good position and energy resolution.

	Effort	Good X-Res	Good E-Res	L Range (meters)	Fuel	Exposure, MW*ton	Running at intended reactor?
US	**PROSPECT**	**Yes**	**Yes**	**6.5-20**	**HEU**	**185**	**Yes**
	NuLat	Yes	OK?	TBD	TBD	TBD	No
EU	STEREO	Yes	OK?	9-11	HEU	100	Yes
	SoLid	Yes	No	6-8	HEU	155	Yes
Russia	DANSS	Yes	No	9.7-12	LEU	2700	Yes
	Neutrino4	Yes	OK?	6-12	HEU	150	Yes
Asia	Hanaro	No	Yes	20-ish	LEU	30	No

B.Littlejohn-Fermilab Intensity Frontier Seminar